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ABSTRACT

This report gives examples of diverse educational strategies in science and engineering education to illustrate the capabilities of the PLATO III computer-based education system. The basic structure of the TUTOR language is discussed and some technical details are given to explain how the PLATO III system works. A brief description of the large-scale PLATO IV system now under development is also given. (Author/FL)

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THE PLATO SYSTEM AND SCIENCE EDUCATION

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The PLATO System and Science Education*

by

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The PLATO III computer-based education system offers students and authors quick response, full graphical display capabilities, and a great deal of number-crunching computing power. The simplicity and flexibility of the TUTOR language, coupled with the ability to switch quickly between writing and testing a lesson, have made the full capabilities of the system easily accessible to users. This environment has given birth to lesson material in a wide range of subject areas, including undergraduate science. Examples are given in this paper of diverse educational strategies in science and engineering education to illustrate these points. The basic structure of the TUTOR language is discussed, and some technical details are given to explain how the PLATO III system works. In closing there is a brief discussion of the large-scale PLATO IV system now being developed.

* To be presented at the Conference on Computers in Undergraduate Science Education, Illinois Institute of Technology, August 20, 1970. Work supported by the National Science Foundation under grant NSF GJ 81; in part by the Advanced Research Projects Agency under grant ONR Nonr 3985(08); in part by Project Grant NPG-188 under the Nurse Training Act of 1964, Division of Nursing, Public Health Service, U.S. Dept. of Health, Education and Welfare; and in part by the State of Illinois.

Lesson Examples

The examples given below are necessarily brief sketches which do not include the details of the complete lessons. Further information about particular lessons may be obtained from the lesson authors, who unless otherwise specified are at the University of Illinois, Urbana. The examples are grouped loosely by subject area. For lack of space these examples do not include a number of important PLATO III activities.

Life Sciences

Computer-generated fruit flies are manipulated by students in a Genetics laboratory designed by Prof. David C. Eades of the School of Life Sciences. Starting with normal and mutant stocks, the student can mate flies of his choice to produce a screenful of computer-generated offspring. (See Figure 1a, which, like the other figures, is an actual photograph of the student's display screen.) He can save any of these offspring for future matings. Through matings and offspring analysis, the student obtains information to elucidate the hereditary mechanism involved in particular mutants. The student always returns to the basic question: "What would you like to do next?", which forces him to design his problem solving procedure.

A lesson on natural selection allows the student to play the role of a bird searching for food. The "food" consists of light and dark moths displayed at random positions on light and dark trees. (See Figure 1b.) The student finds and "eats" most dark moths on light trees, but finds few of the light moths on light trees. The process is continued through several simulated generations of moths to demonstrate the change in gene frequencies. The student thus gains insight about natural selection as a force in evolution. The program was prepared by Prof. Eades and Gary W. Hyatt of the Department of Zoology.

In a maternity nursing course produced by Mrs. Maryann Bitzer and Mrs. Martha Boudreaux of the Mercy School of Nursing, Urbana, Illinois, and Mrs. Elisabeth Lyman of the Computer-based Education Research Laboratory, student-directed inquiry is stressed. Confronted with hypothetical patients and nursing care problems, the students must obtain and select the information necessary to solve problems or answer questions. For instance, in determining the underlying causes of minor discomforts of pregnancy, the student can investigate the anatomic and physiologic changes which occur in various parts of the body, e.g., the uterus, during pregnancy. (See Figure 1c.) The information obtained provides the basis for determining proper nursing strategies to be used in relieving the discomfort. The student is forced to think, investigate and experiment to gather data, categorize information, and test hypotheses, thus developing or reinforcing critical thinking skills.

Prof. Paul Handler of the Department of Physics, assisted by Mrs. Judith Sherwood, has developed a general-purpose demography program which allows a student to make population projections for many countries. Figure 1d shows a graph comparing the numbers of school-age children in the United States and in Mexico for the next one hundred years assuming present birth and mortality rates. Note the "population waves" in the United States data, caused by the depression dip and postwar boom in births. The student can change basic assumptions, such as the average number of children per family, and see the effects of these changes on the population projections. The student can plot many other demographic variables including a bar-graph of the projected age group distribution.

Chemistry

Students can perform multiple-step organic syntheses for electrophilic aromatic substitution reactions by indicating the reagent for each step in the synthesis.

The computer displays the actual product of each specified reaction, checking for compatibility of reagents with functional groups present, reactivity levels, and proper orientation. (See Figure 1e.) Help on the introduction of any functional group is provided. Students are free to choose any sequence of reactions they wish in attempting to synthesize the desired end product. This lesson was developed by Prof. Stanley Smith of the Department of Chemistry.

Experience in rapid identification of unknown organic compounds is provided by a lesson in which the student simply types questions about the compound. (See Figure 1f.) The computer provides essentially instantaneous answers, such as giving the melting point or showing the nmr spectrum of the unknown compound. The vocabulary of the program is adequate to answer almost all of the experimentally useful questions about the compound under investigation. This lesson was also written by Prof. Smith.

A lesson written by Robert Grandey of the Department of Chemistry permits students to generate their own problems or work problems provided in the lesson. (See Figure 2a.) If the student supplies a chemical equation, he can include formulas for molecules, elements, charged ions, and electrons. The computer determines if the equation is balanced both by mass and charge and provides appropriate error messages. Problems of the following types are available:

(1) Determining the chemical formula from the composition by weight.

(2) Calculating the percentage composition from the known chemical formula.

(3) Determining quantitative relations in chemical equations.

The correct answer and specific step-by-step help relevant to the particular problem are generated by the computer. At all times the student may use the computer as a calculator.

Students using a program written by Larry Francis of the Department of Chemistry and Chemical Engineering can work with many more inorganic ion samples than would be possible if they worked only in a chemistry lab. A student adds chemicals from a computer-supplied list to a test tube containing a randomly-generated set of ions. The precipitates and solutes are poured into different test tubes. There are numerous ways to solve each problem and a student is free to try any method he wishes. The computer simulates the laboratory results and reports them to the student (See Figure 2b). Options allow a student to gather additional information about his problem in the way such information is generally available in the lab.

Physics

Students are led to derive kinematics relationships for constant acceleration in a sequence by Prof. Bruce Sherwood of the Department of Physics. The remedial problem at the top of Figure 2c appears if a student gives an incorrect formula for the average velocity. After answering that $\bar{v}$ = 80 fps, the student is shown the inconsistency of his own formula. (The correct expression is $\bar{v} = (v_i + v_f)/2$, where v_i and v_f are the initial and final velocities.) His expression is evaluated for particular values and checked numerically, so equivalent expressions are allowed, such as $\bar{v} = v_i + (v_f - v_i)/2$. In the succeeding steps in the derivation the student eliminates v_f from the expression for $\bar{v}$, then substitutes into the definition $x = \bar{v}\Delta t$ to derive $x_f = x_i + v_i\Delta t + \frac{1}{2}a\Delta t^2$. This sequence is part of a lesson on kinematics which includes tutorial and calculational aspects.

In Figure 2d is shown a very peculiar but correct orbit of a satellite about two stationary "earths" whose centers are marked by the + signs. The satellite was launched with a speed of 7.54 km/sec from the surface of the left "earth". The animated orbit-plotting was stopped by the student, who can now try a different initial speed. The purpose of this simulation is not only to demonstrate motion in an unusual force-field but also to show to the student the power and limitations

of simple numerical integration techniques. The student can specify the integration step size to be used in the calculation and determine his own compromise between speed and accuracy. This simulation was prepared by Prof. Sherwood.

A lesson on quantum statistical mechanics is being developed by Prof. Donald Shirer of the Department of Physics, Valparaiso University. The student chooses N, the number of atoms in his system, and E, the total energy of the system. Figure 2e shows the problem the student now faces: he must specify how many atoms to place on each energy level, consistent with the chosen N and E. The student is led to discover all allowable configurations and their relative probabilities. This leads to a quantitative discussion of the equilibrium distribution as being represented by the most probable configuration.

Engineering

A lesson on Kirchhoff's laws is part of an introductory electrical networks course written by Roger Grossel, a graduate student in Electrical Engineering. For the current law, a network with branch current symbols is displayed. (See Figure 2f.) The student uses the keyboard to assign his own reference directions. He is then asked to type the current law equation for various selected nodes. The computer algorithmically generates the correct answer from the network topology and the student-assigned reference directions. Depending on both the student's answer and student-available options the student is branched to remedial work, the same network, a more difficult network, or to new material. A similar procedure is followed with the voltage law.

In a lesson written by Doug Nyman and Prof. S. J. Fenves of the Department of Civil Engineering, a student may solve problems chosen from a problem library or he may create his own problem by specifying loading and support conditions as shown in Figure 3a. Instructors may define problems in the same way as the student, test them, and then add them to the problem library by using a SAVE option and a pass-

word. In this way new problems can be generated by instructors who do no programming on the PLATO system.

Prof. T. M. Elsesser of the Department of Theoretical and Applied Mechanics is working on a course in statics which is problem-oriented. Figure 3b shows a typical problem and illustrates the use of photographic material in displaying a complex structure to the student.

Other

Here are a few examples from areas outside undergraduate science and engineering which illustrate other kinds of strategies and capabilities.

A lesson for second-graders written by Mrs. Esther Steinberg "gives" the student a specified amount of money and tells him to spend it all on some candy bars. A different price is marked on each kind of candy. (See Figure 3c.) The student may "buy" as many of each kind of bar as he wants as long as he spends exactly the specified amount of money. Since the solution is not unique, he must do some thinking and make practical application of his skill in addition and subtraction.

In a lesson being developed by Paul Tenczar to teach programming to grammar school children, second graders readily learn to "walk" a man around the screen to do work. In Figure 3d the student is well on his way to solving the problem using keys which move the man, pick up a ball, and put down the ball. Other exercises include solving a maze, finding a path home through an alligator-infested swamp, and giving a list of directions for the man to follow (i.e., programming).

One of the techniques used by Prof. Keith Myers of the Department of French and his coworkers is to display a picture of some activity and ask the student to describe the action in French. The student is further aided by non-verbal cues just beneath the picture. In this way the entire presentation can be in French with no English instructions. In Figure 3e the student has answered incorrectly, and the computer has replied not merely by saying "NO" but by crossing out wrong

words and underlining misspelled or nearly correct words. This technique is called "sentence judging" and is a standard feature of the TUTOR language.

Figure 3f is taken from a Russian course prepared by Mrs. Connie Curtin of the University High School. Here the student is practicing translation from Russian into English, and his answer is handled by "sentence judging". In this particular case, upon making an error the student has also been given an acceptable translation at the bottom of the page. When the student is asked to answer in Russian he uses the standard keyboard, but Russian characters appear on his screen as he types.

The TUTOR Language

All of the lessons just discussed were created using the TUTOR language, a language especially designed to simplify the task of writing computer-based educational material for a graphical display terminal. It is impossible to give here an adequate description of TUTOR, but a simple illustration may nevertheless be useful. For a full discussion see "The TUTOR Manual".[1]

The example chosen is a multiplication drill with the problems generated randomly by the computer. In addition to checking for the correct numerical answer, this lesson segment also checks to see whether the student is adding rather than multiplying or whether a wrong answer is within ten percent of the correct answer. After working seven problems the student advances to a division drill.

```
UNIT      INITIAL
ZERO      I10                    Initialize problem counter.
JUMP      MDRILL

UNIT      MDRILL
RANDU     I1,20                  Randomly generate 1≤I1≤20
RANDU     I2,10                                    1≤I2≤10
CALC      I3=I1xI2               Calculate product (I3) and sum (I4)
          I4=I1+I2

WHERE     810                    Display at 8th line, 10th column.
SHOW      I1,3                   Use 3 spaces to show contents of I1.
WRITE      x
SHOW      I2,3
WRITE      =                     For example, the student sees "11 x 9 = "

ARROW     822                    Display an arrow to indicate a response
                                 is required; separate display generation
                                 commands from response judging commands.

ANSV      I3,0                   Check for perfect answer.
ADD1      I10                    If perfect, increment counter and get
NEXT      I10-7,MDRILL,DDRILL    another mult. prob. or go to DDRILL if
                                 7 problems done.

ANSV      I4,0                   Check for sum answer.
WRITE     You're adding!
JUDGE     NO

ANSV      I3,10%                 Check for close answers.
WRITE     You're close!
JUDGE     NO

WRONG                            Anything else.
WRITE     You're way off.

UNIT      DDRILL                 Division drill.
.
.
.
.
```

While this simple example does not demonstrate the full capabilities of TUTOR, it does illustrate some basic features of the language. In unit MDRILL, the student must correctly answer before he can move on to the next problem; when he erases a wrong answer the comment he received is automatically erased, but the problem remains on the screen. The ARROW command separates those commands which set up the original display of the problem from the response-handling commands. The student's reponse will appear on the screen just after the position specified by the ARROW command.

Suppose the problem is "11 x 9" and the student types "95". Then neither the "ANSV I3,0" nor the "ANSV I4,0" specifications are met. The commands following these ANSV commands are ignored. Because the answer is within ten percent of the correct answer, the commands following "ANSV I3,10%" are performed to tell the student "You're close!" and to judge the answer "NO". The student must now erase his answer and try again. On the other hand, after a correct answer the lesson will increment counter I10 and go to the next problem. Note that TUTOR often executes commands in a contingent rather than linear order. The "NEXT I10-7,MDRILL, DDRILL" is an example of branching which depends on the value of the computed quantity, "I10-7".

TUTOR authors can use up to 139 variables, labeled 1 through 139. A single letter preceding the number indicates the format of the variable: I for integer, F for floating point, and A for alphanumeric. In this multiplication drill, integer variables are used to generate a problem, to calculate expected answers, and to count how many problems have been completed.

While this drill emphasizes one particular kind of numerical judging, using the ANSV command, there are many other answer-judging commands and techniques available in TUTOR for handling numerical and non-numerical student responses.

Technical Details

The PLATO III system is based on a graphical display terminal which is x-y-addressable and has its own storage-tube memory to free the computer from the burden of refreshing the display. Computer generated material--alphanumeric text, lines, and special characters--is written on the storage tube in a point by point fashion. The material on the storage tube is mixed with photographic material from a slide selector (if desired) and presented on a standard TV screen.

The system is oriented around core memory rather than disk memory. No disk accesses are made for students while they are studying a lesson: the lesson material and the pointers and counters pertaining to the individual student reside in core. The elimination of disk accesses during lesson presentation results in much faster response than is typical in multi-terminal systems.

The PLATO III computer is a CDC 1604 with 32000 (32K) 48-bit words. Half of core (16K) is occupied by the TUTOR executor and other system routines. Of the other 16K, 10K is reserved for lesson material and 6K is divided into 20 "student banks" of 300 words each. These 20 student banks contain the complete status of the individual students signed on at each of the 20 terminals. A student bank contains the 139 TUTOR variables, answer storage, pointers marking the student's place in his particular lesson, and other systems variables. Typically a student works through approximately 3K of lesson material in an hour. During a Russian class the students might be spread over 7K of lesson material, so that 3K of lesson space would be available to chemists or political scientists for debugging their own lessons.

The integration of the three major blocks of core (executor, lesson material, and student banks) can best be described by following the sequence of operations initiated by a student pushing a key on his keyset. The keypush interrupts the

computer, which pauses just long enough to add the key and its accompanying terminal identification number to a list. Eventually the computer services this request, at which point the terminal identification number is used to reference the correct student bank. Often the only operation required is to write the letter corresponding to the keypush on the student's display screen. It is important, however, to point out that any keypush may generate an "unusual" letter (Russian for example), an accent mark, etc., or initiate a complex display. For this reason it is essential that all keypushes pass through the main computer to be processed.

Which lesson the student is studying, and where he is within the lesson, are specified by words of student bank. These are used when necessary to reference the lesson material, which is examined by the executor to determine what to do for this student. As outlined in the discussion of the simple multiplication drill, the TUTOR executor judges the student's response and replies to him by performing those commands which follow the ARROW command. The data pertinent to this particular student are found in his student bank. If the computer's reply consists of a small amount of computer-generated text or graphics to be added to the display now on the screen, the reply appears almost instantaneously. If a completely new display is to be generated, the speed of the reply is determined by the characteristics of the storage cathode-ray tube: a full screen of text and graphics takes one to two seconds. For example, the fruit flies of Figure 1a appear in two seconds. (On the other hand, the full-screen nursing display of Figure 1c appears instantly because it comes from the slide selector rather than being generated.) The average reply time (including short and long replies) is between one- and two-tenths of a second.

This summarizes the major steps taken in processing a student's keypush. No disk accesses are required while the student studies his lesson. Both his lesson and his particular variables are in core memory at all times. (Student sign-on

and sign-off do however generate disk accesses to get and to file away essential portions of his student bank.)

At any time a teacher can type a code word and put his terminal into "author mode". Authors are permitted disk accesses to edit alphanumeric text and to compile that text into the lesson area of core memory. These operations do not conflict with the simultaneous use of other terminals by other students and authors. (However, a compilation, which typically takes 15 seconds, locks out compilations by other authors during that time. This does not affect student use and text editing by other authors.)

TUTOR lessons are kept on disks in blocks of approximately 50 lines. When an author edits his lesson he specifies the block he wants to work on. It is read from the disk into the author's "student bank", where the text is available for editing without further disk references. The first fifteen lines of lesson text in the selected block are displayed. The author may move forward in the block to display later lines. He may insert, delete, replace, or copy lines or portions of lines. He can save a group of lines and deposit them elsewhere, even in other blocks, and entire blocks can be copied from one lesson to another. Within a line he can insert, delete, or replace characters. When the author is satisfied with the newly edited form of the block, he returns the block to the disk.

To test a lesson the author specifies which lesson or lessons he wishes to compile. Within about 15 seconds the alphanumeric text is compiled from the disk into the lesson area of core memory. Any errors discovered by the compiler are displayed. (After processing each line of text the computer services any new student keypushes, thereby not delaying any student operations.) The author can then work through his lesson as a student. He may encounter things he doesn't like, or he may get an error message. At any time he can return to author mode, delete the compiled version from memory, modify the lesson text, and test it again.

The simplicity and speed of these author mode operations coupled with the power of the TUTOR language make the system attractive to teachers from many subject areas. Many of the successful authors using PLATO III had little or no previous computer experience. Authors need no middlemen; this greatly enhances acceptance and efficiency and encourages continual lesson improvement. The wide range of author interests and disciplines has produced continual evolution of TUTOR under the pressure of diverse needs. This evolution has acted at both ends of the spectrum, making simple lessons even easier to write and making possible more complex simulations and teaching strategies.

The PLATO IV System

We have discussed the hardware and software features of the PLATO III system which support science and engineering curriculum development. In closing it is appropriate to look briefly at the large PLATO IV system now being developed.

The PLATO IV design includes a large central computer system of the CDC 6000 series to handle simultaneously four thousand remote graphics terminals at projected costs of 35¢ to 50¢ per terminal hour. The capabilities of the remote terminal exceed those of the PLATO III terminal, through use of the plasma display panel, whose inherent digitally-addressable memory makes possible high-quality graphics with low data transmission rates. The panel is flat and transparent, which permits the superposition of computer-generated graphics with rear-projected full-color film images. The PLATO IV terminal contains a character generator and a line generator, as well as other built-in functions. (For details on the over-all PLATO IV system design, see Bitzer & Skaperdas[2]. For a discussion of some of the implications, see Alpert & Bitzer[3].)

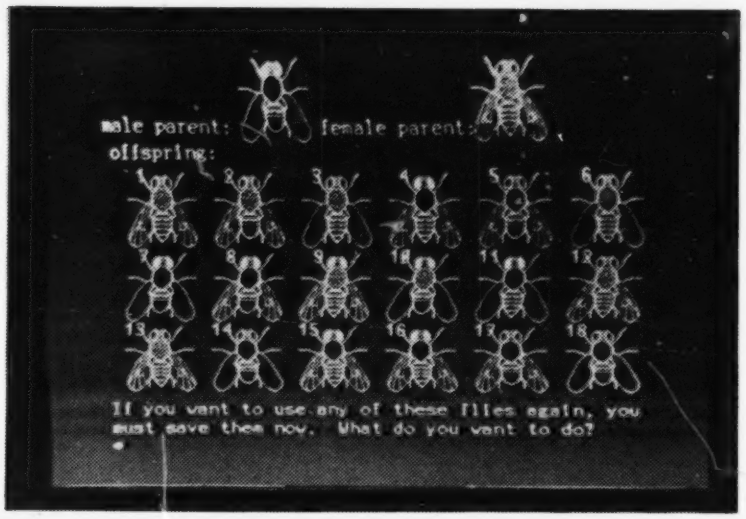
Lesson material and TUTOR software already created on PLATO III will be operable on PLATO IV. The student banks and lesson material will reside in an auxiliary core memory (Control Data "Extended Core Storage" or ECS). When needed, portions or all of a particular student bank and related lesson material can be rapidly transferred from ECS into the computer's central memory. It is planned that the PLATO IV system will have two million 60-bit words of ECS, an amount which should be sufficient to hold 4000 student banks plus 250 hours of lesson material. Thus, at any one time, students would have access to about 250 lessons selected as needed from a large disk lesson library.

References

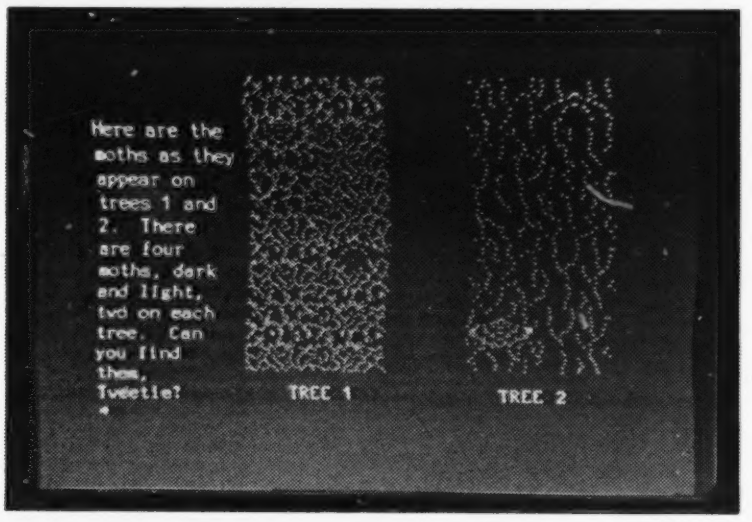
1. R. A. Avner, Paul Tenczar, "The TUTOR Manual," CERL Report X-4 (Computer-based Education Research Laboratory, University of Illinois, Urbana.) January, 1969.

2. D. L. Bitzer, D. Skaperdas, "PLATO IV--An Economically Viable Large-Scale Computer-based Education System," presented at the National Electronics Conference, Chicago. CERL Report X-5 (Computer-based Education Research Laboratory, University of Illinois, Urbana.) December, 1968.

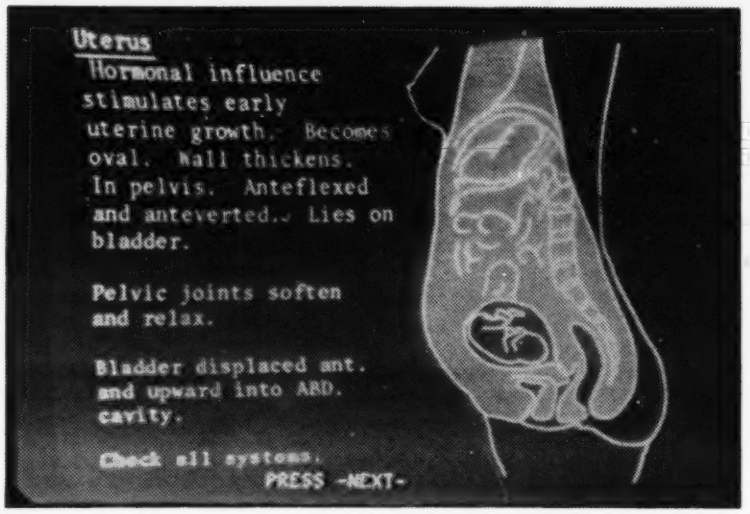
3. D. Alpert, D. L. Bitzer, "Advances in Computer-based Education," Science, 167, 1582 (1970).



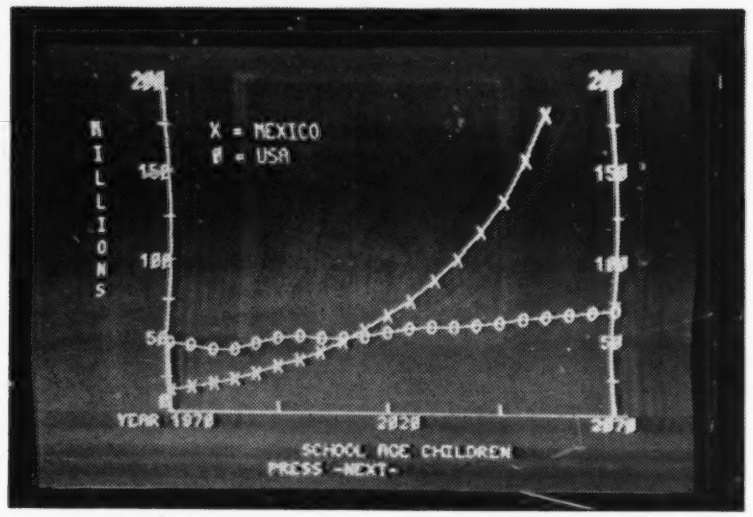
a) Fruit Fly Genetics


Here are the moths as they appear on trees 1 and 2. There are four moths, dark and light, two on each tree. Can you find them, Tweetie?
TREE 1
TREE 2

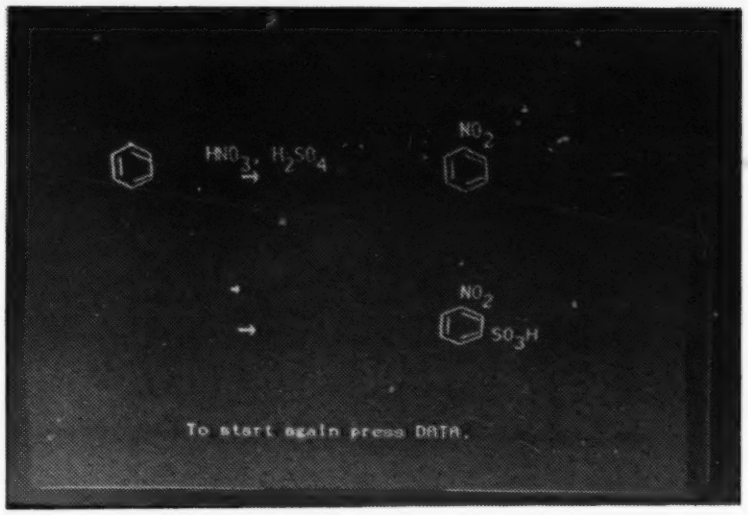
b) Moth Evolution


Uterus
Hormonal influence stimulates early uterine growth. Becomes oval. Wall thickens. In pelvis. Anteflexed and anteverted. Lies on bladder.
Pelvic joints soften and relax.
Bladder displaced ant. and upward into ABD. cavity.
Check all systems.
PRESS -NEXT-

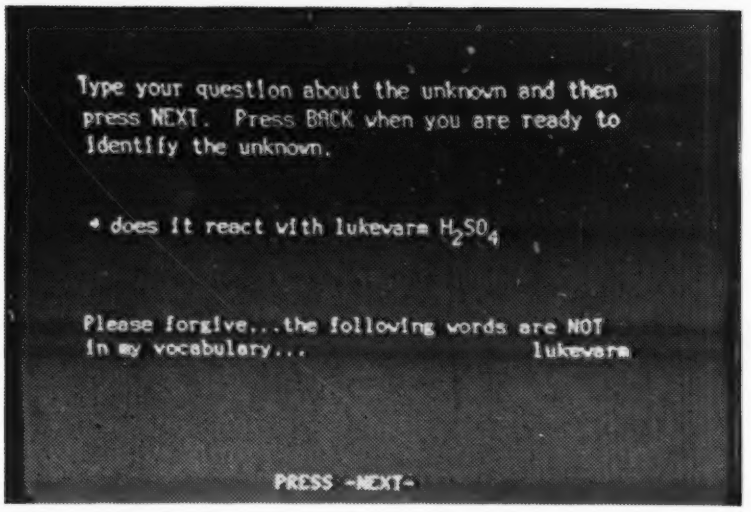
c) Maternity Nursing



d) Demography

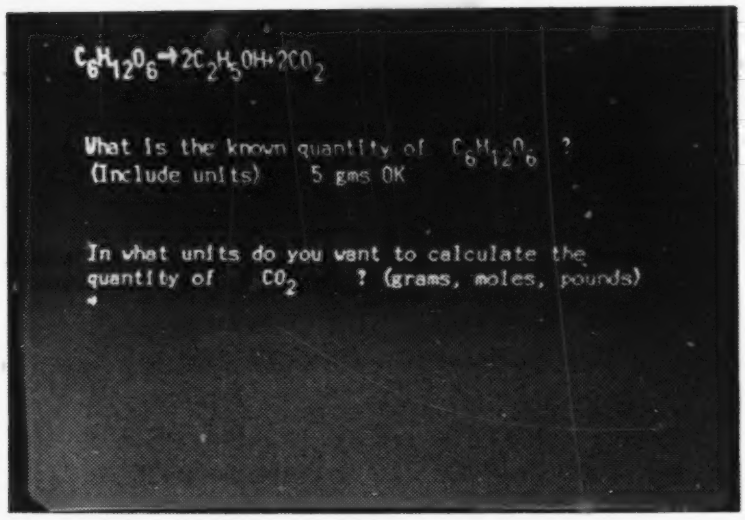


e) Organic Synthesis

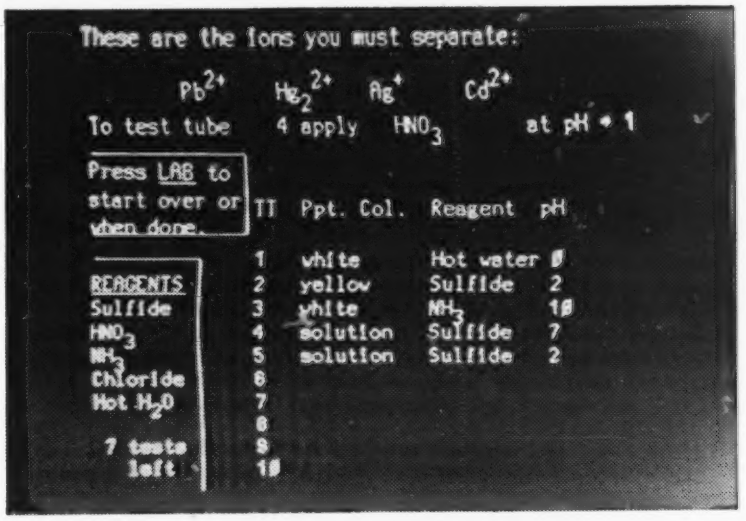

Type your question about the unknown and then press NEXT. Press BACK when you are ready to identify the unknown.
• does it react with lukewarm H_2SO_4
Please forgive...the following words are NOT in my vocabulary... lukewarm
PRESS -NEXT-

f) Organic Qualitative Analysis

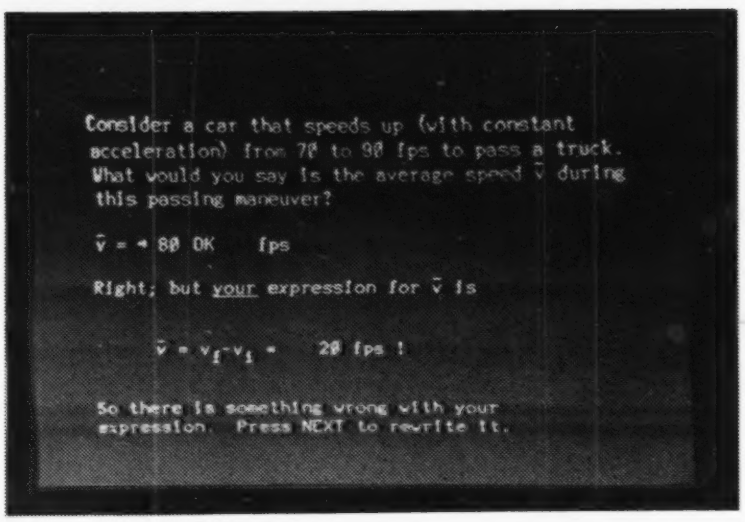
FIGURE 1. PHOTOGRAPHS FROM PLATO LESSONS


$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$
What is the known quantity of $C_6H_{12}O_6$?
(Include units) 5 gms OK
In what units do you want to calculate the quantity of CO_2 ? (grams, moles, pounds)
•

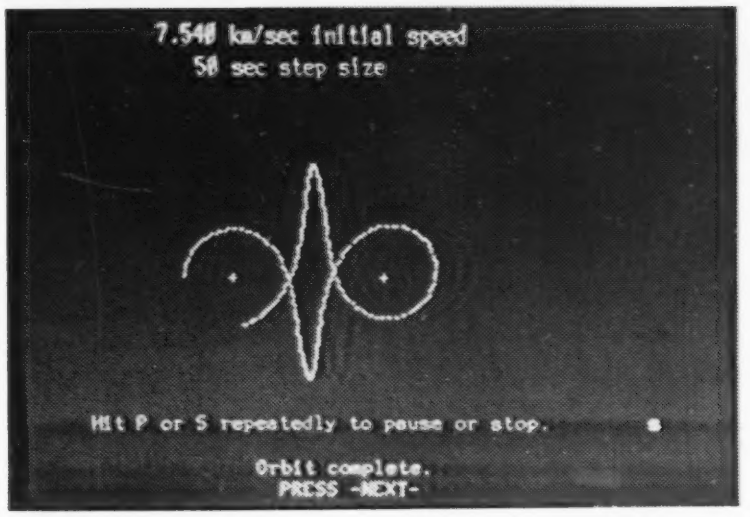
a) Chemical Equations



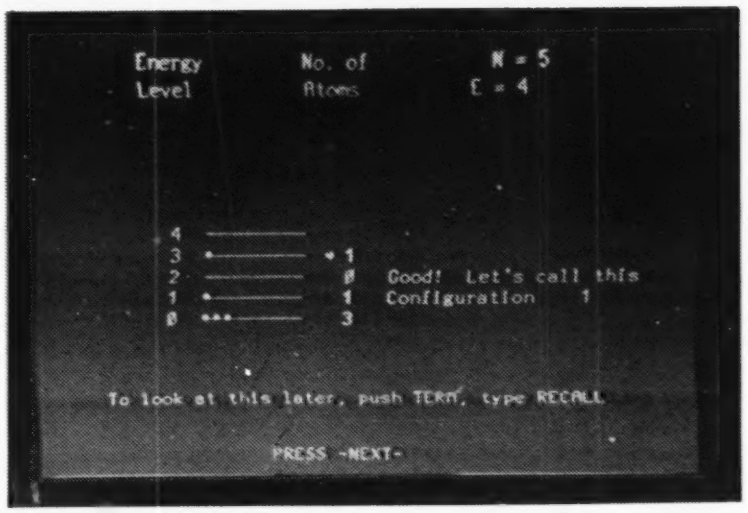
b) Inorganic Qualitative Analysis


Consider a car that speeds up (with constant acceleration) from 70 to 90 fps to pass a truck. What would you say is the average speed $\bar{v}$ during this passing maneuver?
$\bar{v}$ = 80 OK fps
Right; but your expression for $\bar{v}$ is
$\bar{v} = v_f - v_i$ = 20 fps !
So there is something wrong with your expression. Press NEXT to rewrite it.

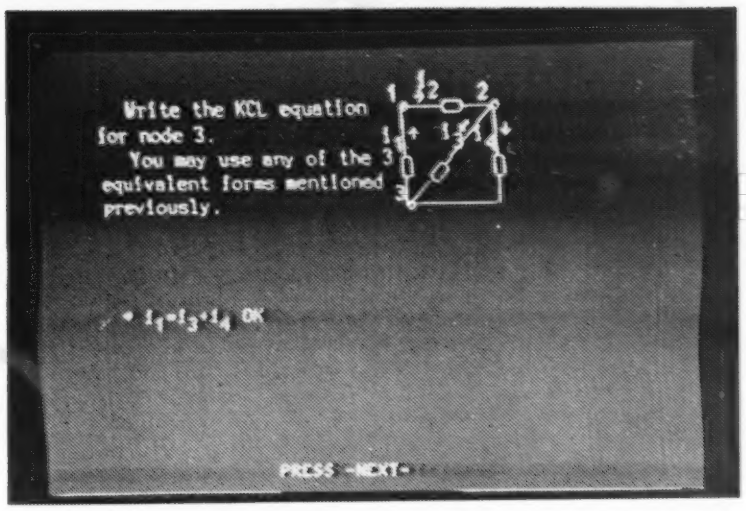
c) Kinematics



d) Gravitational Orbits

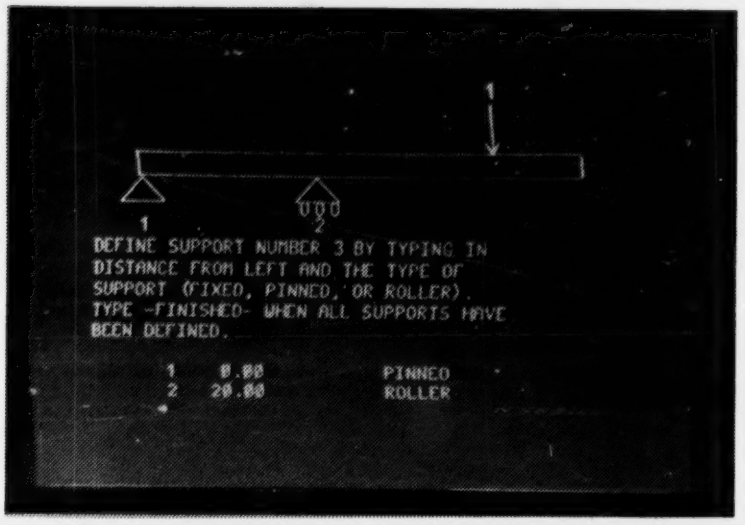


e) Quantum Statistics

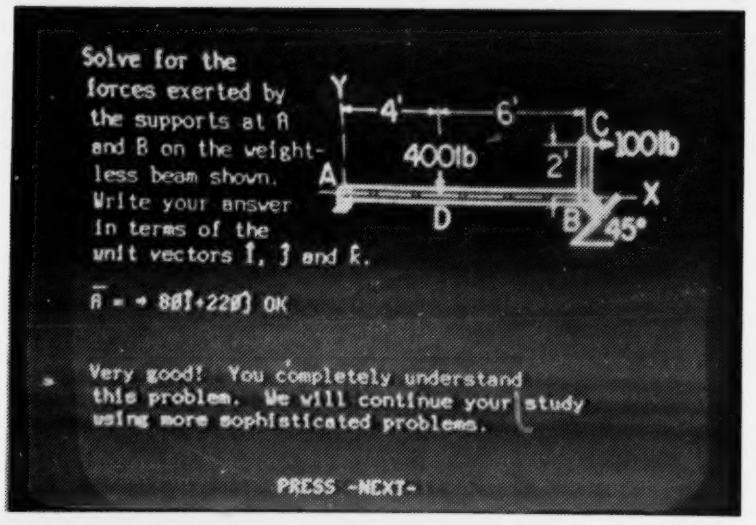


f) Electrical Networks

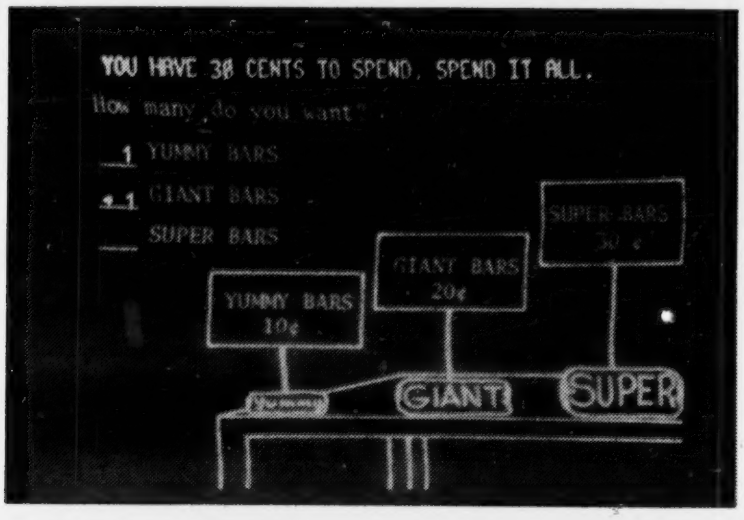
FIGURE 2. PHOTOGRAPHS FROM PLATO LESSONS



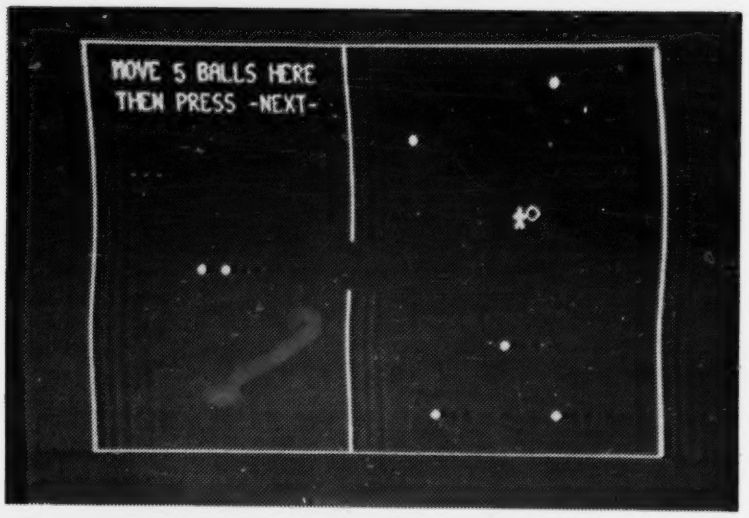
a) Beam Loading



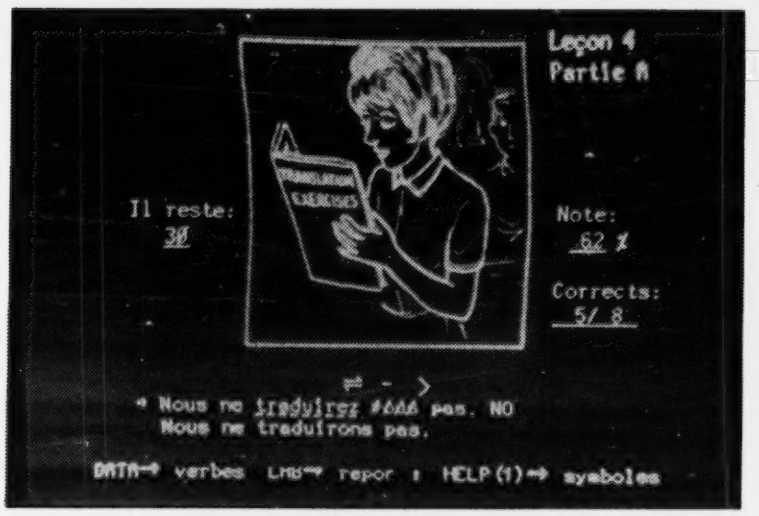
b) Statics



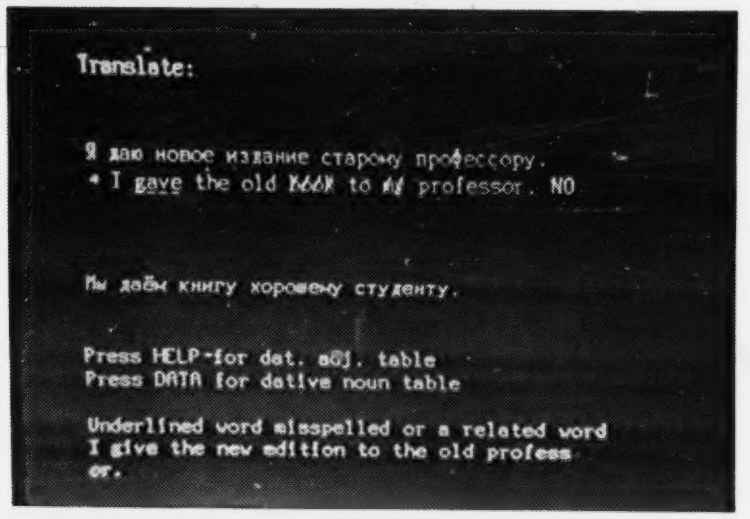
c) Arithmetic



d) Simple Programming



e) French


Translate:
Я даю новое издание старому профессору.
I gave the old book to my professor. NO
Мы даём книгу хорошему студенту.
Press HELP-for dat. adj. table
Press DATA for dative noun table
Underlined word misspelled or a related word
I give the new edition to the old profess
or.

f) Russian

FIGURE 3. PHOTOGRAPHS FROM PLATO LESSONS

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13. ABSTRACT

The PLATO III computer-based education system offers students and authors quick response, full graphical display capabilities, and a great deal of number-crunching computing power. The simplicity and flexibility of the TUTOR language, coupled with the ability to switch quickly between writing and testing a lesson, have made the full capabilities of the system easily accessible to users. This environment has given birth to lesson material in a wide range of subject areas, including undergraduate science. Examples are given in this paper of diverse educational strategies in science and engineering education to illustrate these points. The basic structure of the TUTOR language is discussed, and some technical details are given to explain how the PLATO III system works. In closing there is a brief discussion of the large-scale PLATO IV system now being developed.

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